MEASURES OF INSECT COLD HARDINESS.

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Different measures of insect cold hardiness used by different workers may usually be reduced to the empirical survival test. Bachmetjew (1901) used the "vital temperature maximum" or the second time an insect reached the undercooling point. Duval and Portier (1922) considered that there was a freezing point below that ordinarily determined, the higher freezing point being that of the body fluids, the lower that of the body cells.

In strong contrast to the scarcity of measurements of insect cold hardiness, stand the many determinations by plant physiologists. Osmotic pressure as determined by freezing point lowering has been widely used from the time of Sachs and Pfeffer. Water content has been of value as a criterion of cold hardiness in plant groups far separated taxonomically. For example, Johnson (1923) used water content of peach buds as a measure of cold hardiness, and Steinbauer (1926) employed it for clover seeds. Newton and Gortner (1922) and Newton (1924) emphasize the importance of bound water to cold hardiness. Müller-Thurgau (1886) proved conclusively that some plants could survive freezing. The ability of a plant to survive freezing was defined by Harvey (1918) as cold hardiness.

The two kinds of insect cold hardiness (1) hardiness to the quantity factor of low temperature or ability to withstand long periods of relatively mild low temperature and (2) hardiness to the intensity factor of low temperature, or ability to withstand extremes of low temperature have been discussed in a previous paper. In the present paper cold hardiness to the intensity factor alone will be considered.

Closely associated with changes in cold hardiness are changes in moisture content. Insects dehydrated but not to the period of injury, can withstand temperatures far lower than undehydrated individuals. This is strikingly true for insects that are not self dehydrating to any large extent. Thus the Japanese beetle, *Popillia japonica* Newm., does not exhibit any marked body weight changes over winter when kept in moist surroundings, but can be experimentally dehydrated to half its body weight. When thus treated they are very cold resistant, having a survival temperature of as low as − 28° C. In contrast to the Japanese beetle larvæ there are some species of oak borers and caterpillars which are normally self dehydrating during the winter. The dehydration curves (Fig. 1) of *Isia isabella* Hy. Edw. and *Diacrisia virginica* Fabr. show a marked water loss as these caterpillars go into hibernation. At the period of inflection

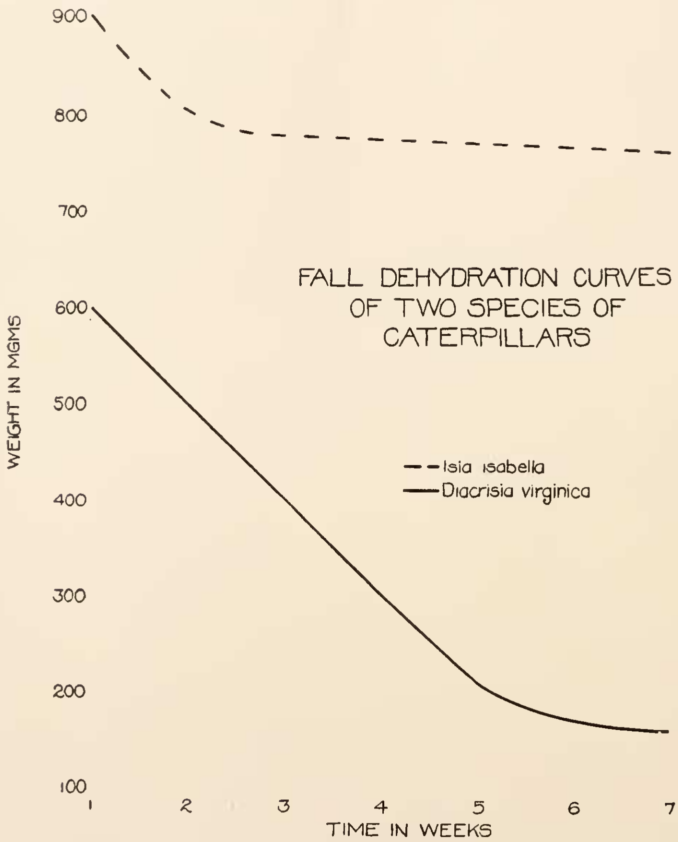

FIG. 1. Fall dehydration curves of two species of caterpillars, *Isia isabella* and *Diacrisia virginica.*

of the weight loss curve (Fig. 1) these insects can survive freezing. When the curve is plotted with rate against weight loss the point of inflection is brought out more clearly (Fig. 2). Up to the point of inflection of the weight loss curve the undercooling point of the blood is the minimum survival temperature. Beyond that point the undercooling point no longer measures the total cold hardiness which reaches to below − 40° C. There is no free body fluid on which a conductivity reading can be made.

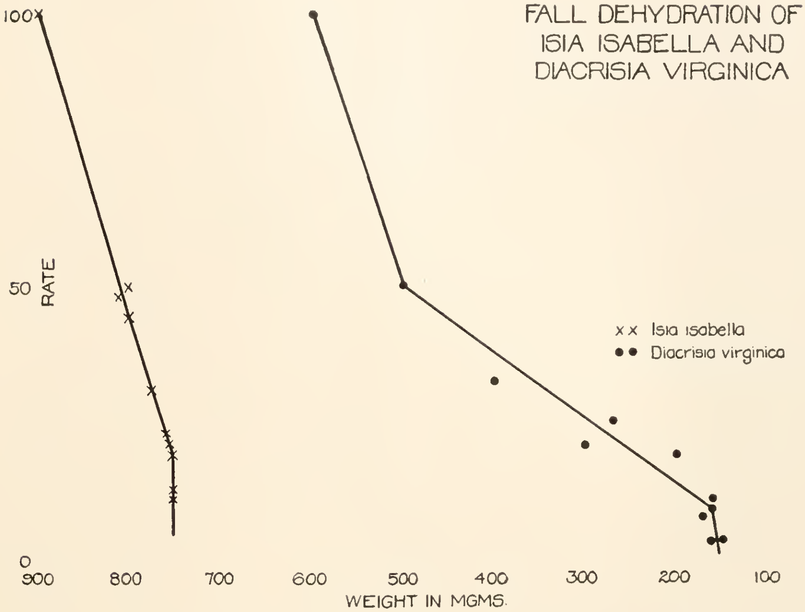

FIG. 2. Fall dehydiation of *Isia isabella* and *Diacrisia virginica*. $\frac{1}{\text{time}}$ or rate plotted against weight.

The oak-borers, *Synchroa punctata* Neum., *Dendroides canadensis* Lec., *Romaleum rufulum* Hald. also are normally self dehydrating but never to the extent of losing all their free water. Although very cold resistant, having survival temperatures of below − 40° C., at no time even in the deepest winter, is it impossible to obtain blood samples. But conductivity is found to be proportional to the survival temperature (Fig. 3). The water content of these insects, obtained by heating them in an oven for four hours at + 50° C., is only relative but does appear

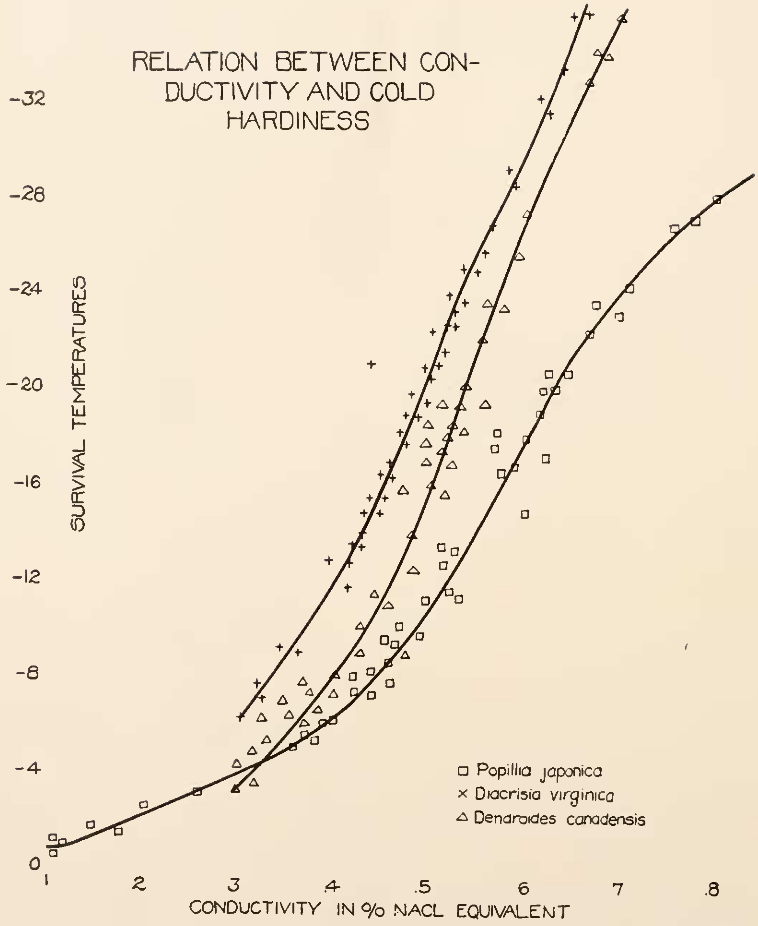

FIG. 3. Relation between conductivity and cold hardiness. *Popillia japonica* □, *Diacrisia virginica* ×, *Dendroides canadensis* △.

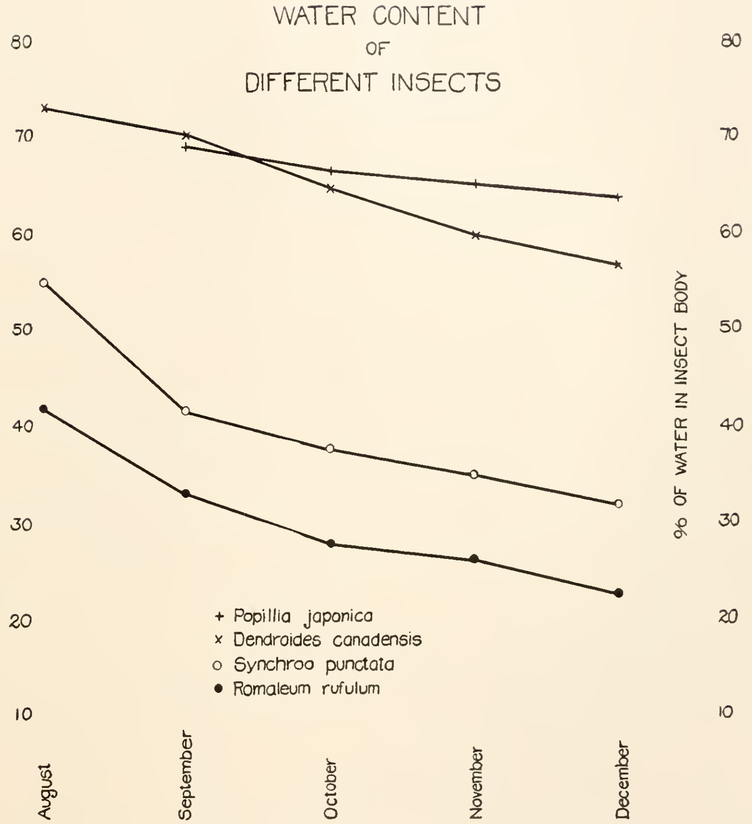

FIG. 4. Water content of different insects during the season at which they develop cold hardiness. *Popillia japonica* +, *Dendroides canadensis* ×, *Synchroa punctata* o, *Romaleum rufulum* ●.

to give comparable results with different species. The per cent. of water before and during hibernation of three species of oak-borers and of the Japanese beetle are shown in Fig. 4.

The Japanese beetle larvæ, *Popillia japonica* Neum. represent an ecological group far more protected than either the oak-borers or the woolly bear caterpillars. This species hibernates in the ground below the frost line. About 97 per cent. are third instar larvæ and about 3 per cent. second instar. There is a cyclic change in the cold hardiness of these larvæ, not as marked, however, as in the oak-borers but more apparent than in the

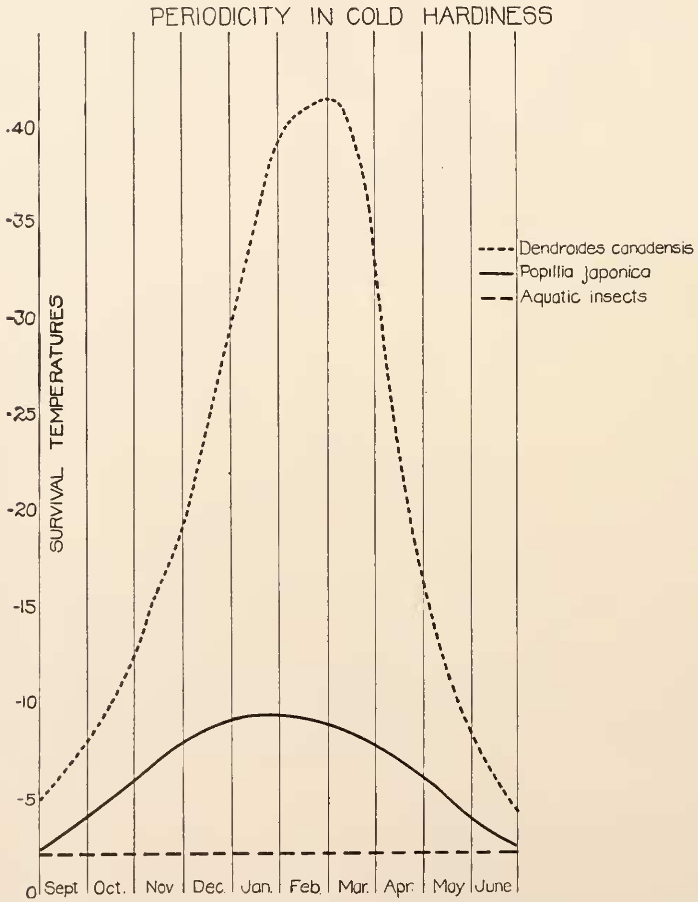

FIG. 5. Periodicity in cold hardiness. *Dendroides canadensis* – – –, *Popillia japonica* ——, aquatic insects — —.

aquatic insects where there is practically none, Payne (1926). This periodicity in cold hardiness is shown in Fig. 5. The relation between undercooling and survival temperatures is shown in Fig. 6. Cold hardiness greater than is usually found in their soil habitat can be induced in this insect by dehydration. Conductivity measurements of the blood of dehydrated insects were made. The greatest cold hardiness was found in the dehydrated insects and the least in those infected with wilt disease or

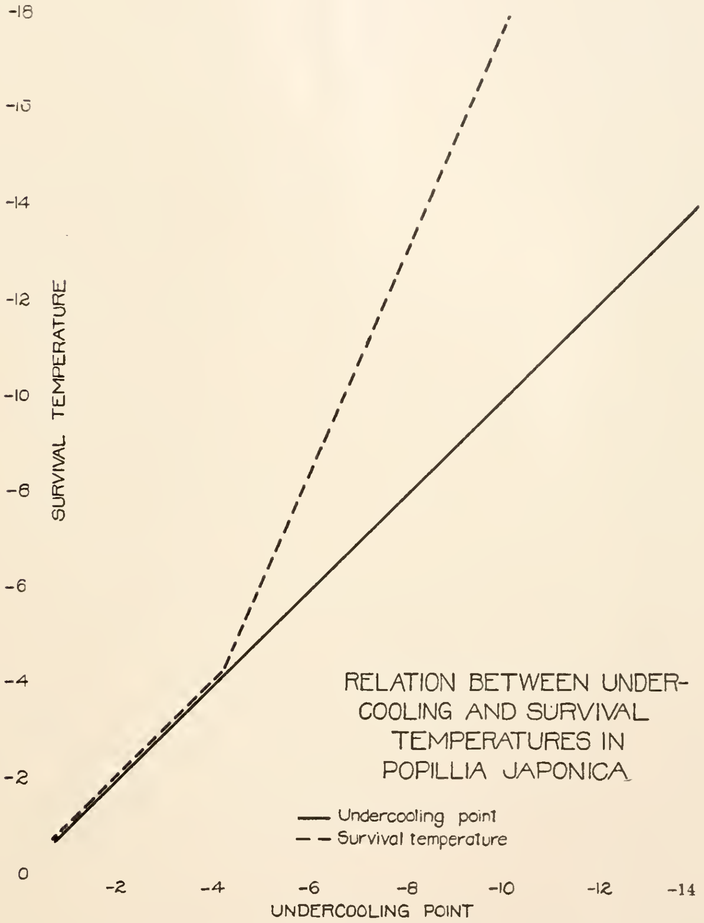

FIG. 6. Relation between undercooling and survival temperatures in *Popillia japonica*. Undercooling point ——; survival temperature — —.

polyhedrälskrankheit. In this disease both the freezing point and the conductivity of the blood approach that of water. In Fig. 3 the conductivities of the Japanese beetle larval blood are plotted against survival temperature. Cold hardiness in this species is more fully measured by conductivity than by either moisture content or undercooling point.

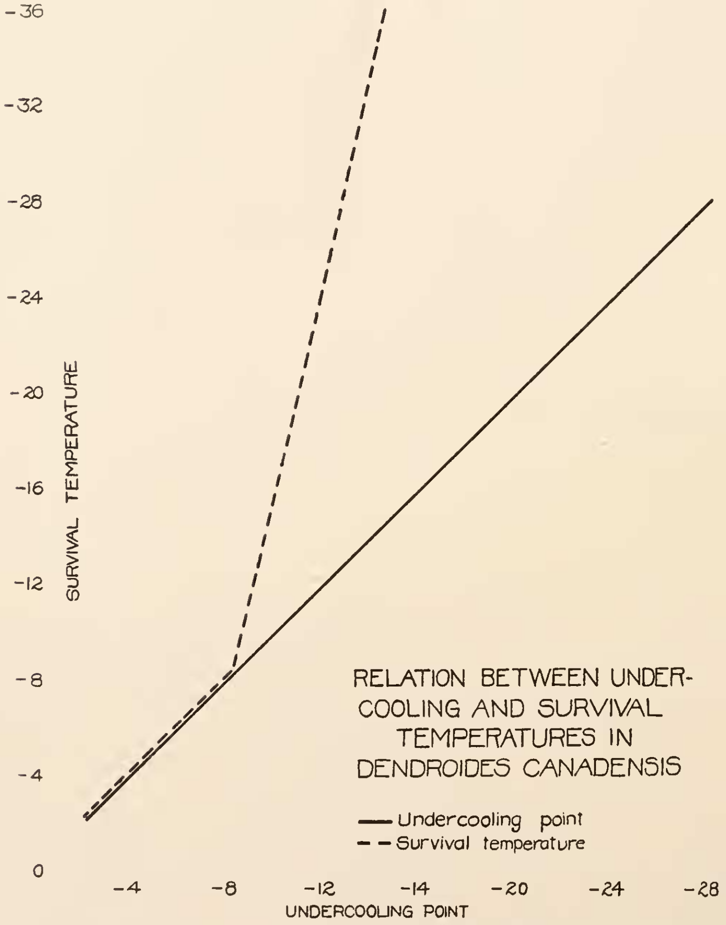

Fig. 7. Relation between undercooling and survival temperatures in *Dendroides canadensis*. Undercooling point ——; survival temperature — —.

SUMMARY.

1. Cold hardiness to the intensity factor of low temperature can be measured by moisture content, undercooling point, and blood conductivity.

2. Up to the time when a given insect can survive freezing, undercooling is a reliable measure of cold hardiness. Beyond the point when an insect can survive freezing, undercooling measures but a part of the total cold resistance of a given insect.

3. Conductivity measurements are found proportional to cold hardiness throughout the whole year. In some insects there is insufficient free body fluid in winter on which to determine blood conductivity.

4. For each species there is a different set of physical constants which measure the cold hardiness of that species.

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